A Re-Introduction to the "Anomalies of Criticality"

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I AM…

- The B.M. Durst You See in the Literature
- I Go by "Mike"
- I Was the Last Certified/Qualified Senior Experimenter at the Pacific Northwest National Laboratory CML

THIS IS…

- A Dubious Title in That There Were Only a Half-dozen Like Me at Battelle and Only Another Handful of Us in the History of the Entire CML DOE Complex
- It Taught Me to Look at the CML or for That Matter Any CML in a Different Way

I am Here Today To.....

- Re-Introduce you again to the "Anomalies of Criticality"
- I do this because I believe it is one of the very best primers on criticality and should be included in all Criticality Training Programs as "Must" reading

In fact….

- It is already included in most training programs as suggested reading
- **DOE-STD-1135-99, "Guidance for Nuclear Criticality Safety Engineer Training and Qualification"** references it as one way to acquire knowledge about criticality accidents and critical experiments in general

Why is it such a special document?

- As an experimenter, I came to appreciate the subtleties of taking things critical.
- There were some basic safety rules that were always applied.
- When actually going critical, every effort was taken to ensure adequate safety measures were in place to protect you as an experimenter and of course the public.
- In a sense, "Anomalies of Criticality" is a condensation of tens of thousands of experimental results on all kinds of critical systems over a fifty year period of time.

Why As A Criticality Analyst Do you Need to Know about "Anomalies?"

- On a daily basis you define limits and specifications for the safe handling of materials in your facility
- You need to know that sometimes, "Things aren't as expected"
- If you will learn to appreciate this, you will build into your evaluations and documents better controls for your materials.
- You will avoid the miss-cues of others.

Anomalies of Criticality – Its Genesis

- The original document (Rev.0) was issued in 1974 by E. D. (Duane) Clayton, then manager of the Battelle Critical Mass Laboratory
- This was vital to the Hanford mission of extracting plutonium and uranium from the reprocessed production reactor fuels.
- We used it in our experimental planning in our establishing the safe bases for our materials storage.

What’s new in revision 6?

- Physical characteristics of the actinides
- Safety Implications of Anomalous effects of neutron absorbers on criticality
- Interstitial moderation and its importance to criticality
- Geometry effects
- Universally safe containers
- Super-heavy elements and an island of stability beyond Californium

To Appreciate "Anomalies…."

- You must first understand the process of taking things critical
- Let's take a short walk through my early life as an experimenter.

THE CAPABILITIES AND LEGACY….

- The CML Collected Much of the World’s Data on Plutonium Solutions
  - Tens of Thousands of Critical, Delayed Critical and a Few Sub-critical Experiments Conducted
  - All Different Types of Geometries
  - Both Heterogeneous and Homogeneous Data
  - Poisoned and Non-poisoned Systems

THE CAPABILITIES AND LEGACY… (con't)

- Types of Experimental Data Collected: Solution Hood
  - Pu Solutions, Multiple Ranges of Concentrations and 240 Content
  - Highly Enriched Uranium Solutions
  - U-233 Solutions
  - World's Largest Solution Critical Experiment (The Eta Sphere)
  - Solid and solution mixtures: You Name the Shape and We Did It

THE CAPABILITIES AND LEGACY… (con't)

- Split Table Data:
  - Pu Blocks (Metal, Oxide, Varying Concentrations and 240 Content)
  - U-233 Solutions in Small Bottles
  - Pu Solutions in Bottles
- Interacting Array Assembly Data:
  - Clusters of Fuel Rods: Different Pitch, Fuel Type and Reflectors
  - Solid and Liquid Poisoned Systems
  - Pu or Uranium Systems

THE CAPABILITIES AND LEGACY… (con't)

- Subcritical Portable Systems Data:
  - - Cask Keff
  - - N Reactor Fuel Cluster Keff vs.B/u
  - - Keff for both Pu and U Systems as a Function of Approach to Critical
  - - Cribs/boreholes in 200 E & W Areas

The experiments were conducted in an Experimental Facility That….

- Was a Rectangular Facility, Housing A 35 x 35 Ft. Critical Assembly Room, a Supplemental Chemical Mixing and Storage Area, and an Admin. Section
- The Cell Had Concrete Walls of Reinforced Concrete 5 ft. Thick.
- On One Side Was a Three-foot Thick Access Door For Entry of Large Equipment

INSIDE THE CRITICAL ASSEMBLY ROOM…

- There Were Five Major Areas for Conduct of Experiments
  - The Solution Critical System
  - The Remote Split Table Machine System
  - The Assembly for Interacting Arrays
  - The Interacting Solutions Tank
  - A Fifth System, a Subcritical Measurement System Was Portable

Outside the Room and in the Mixing Area…

- Solution Slab Tanks and Mixing Hoods Were Housed in the Mix Room
- Slab Tanks Were Designed Based on Initial Lab Critical Experiments
- Many of These Concepts Are Universally Used in the Industry Today

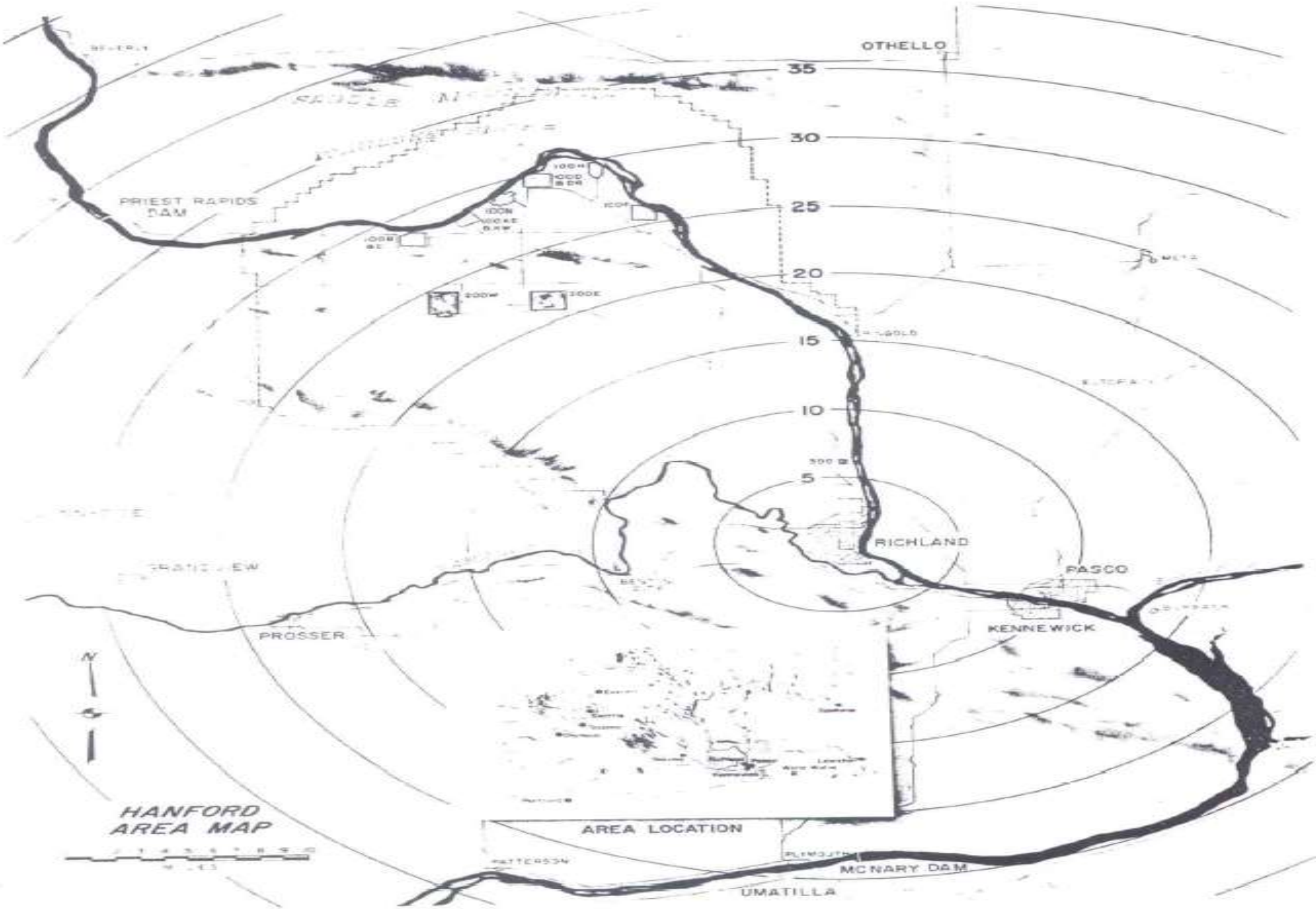

Figure 2. Site Location of Critical Mass Laboratory

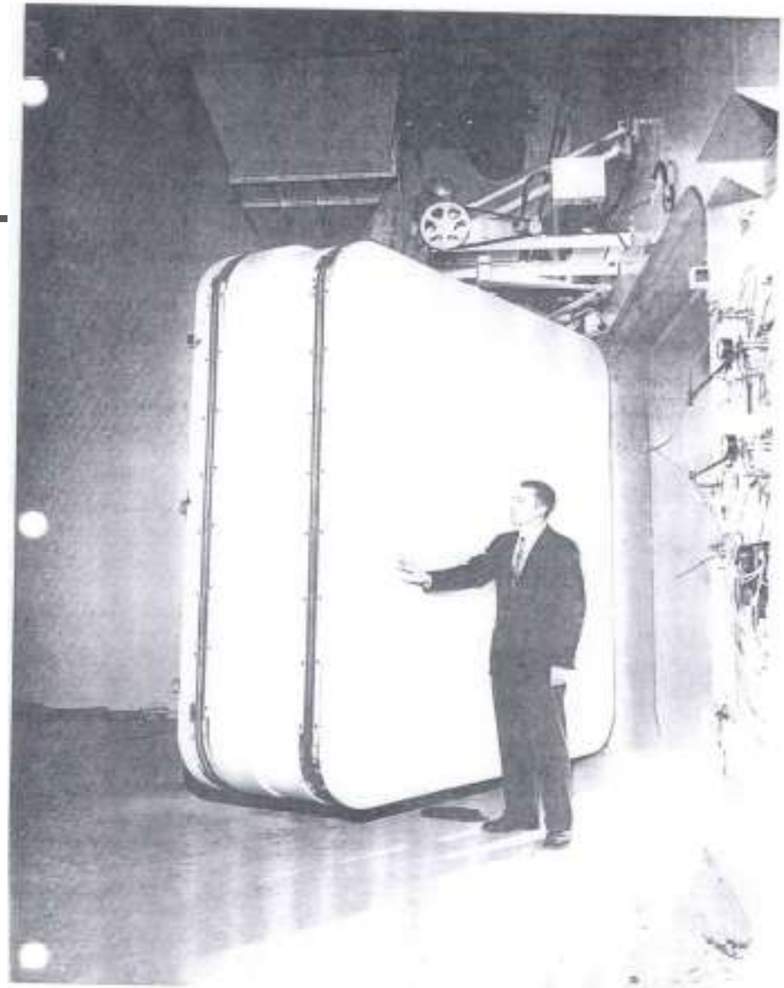

Figure 5. Shielded Door of Critical Assembly Room for Major Equipment Access

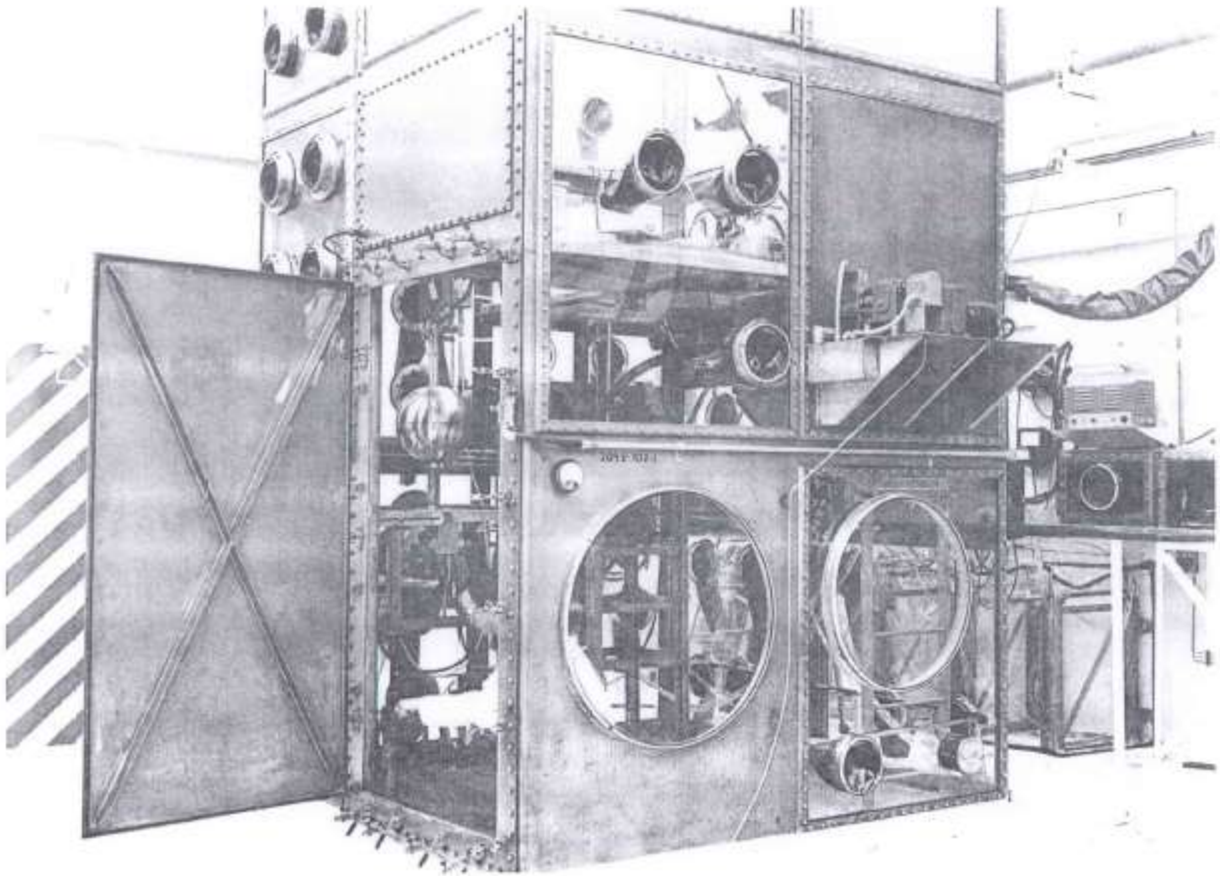

Figure 6. Containment Structure for Solution Critical Experiment Equipment

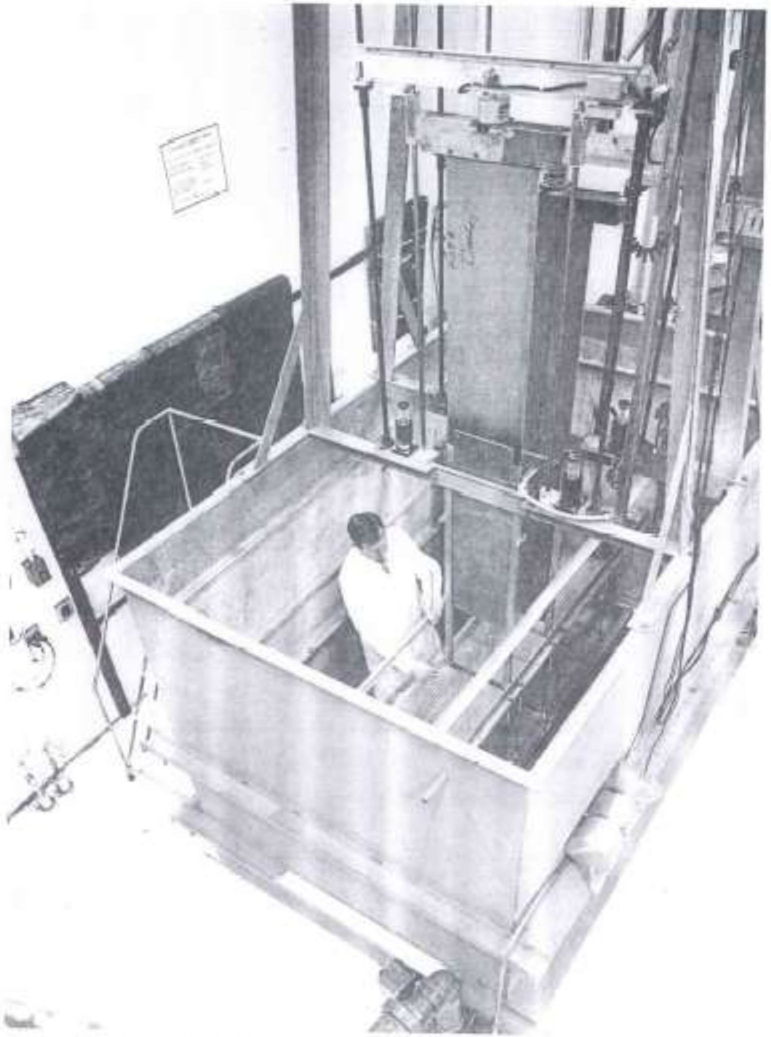

Figure 8. Facility for Studying Criticality of Arrays of Fuel Elements in Water

MIX HOOD SLAB TANK ARRAY

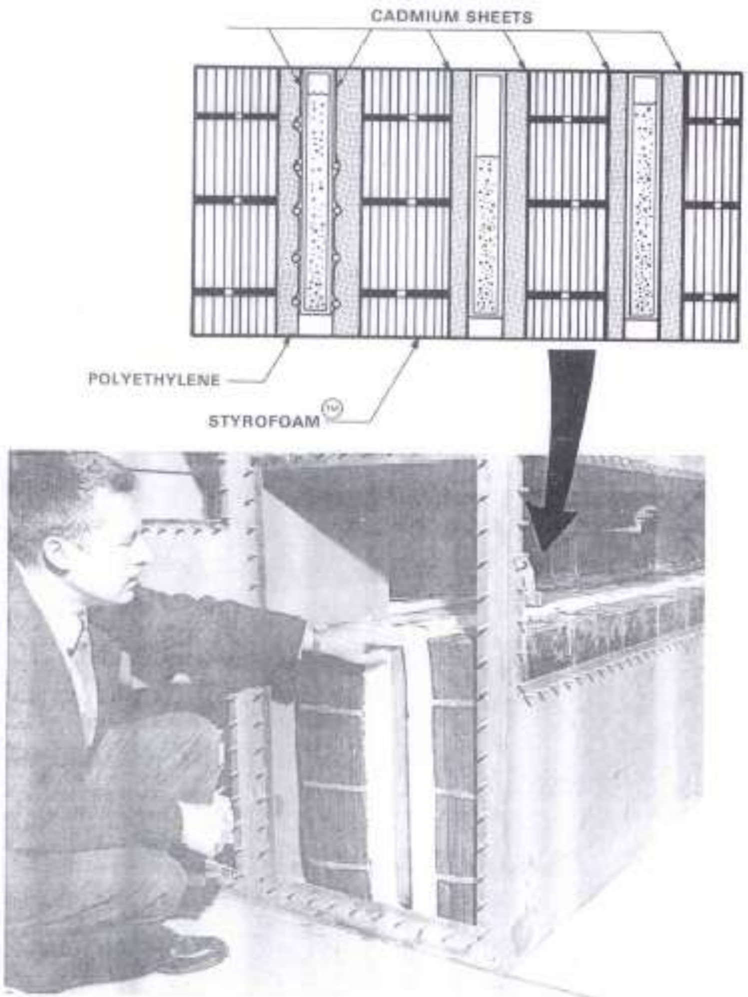

Figure 11. An Arrangement of Slab Tanks for Safely Handling Solutions

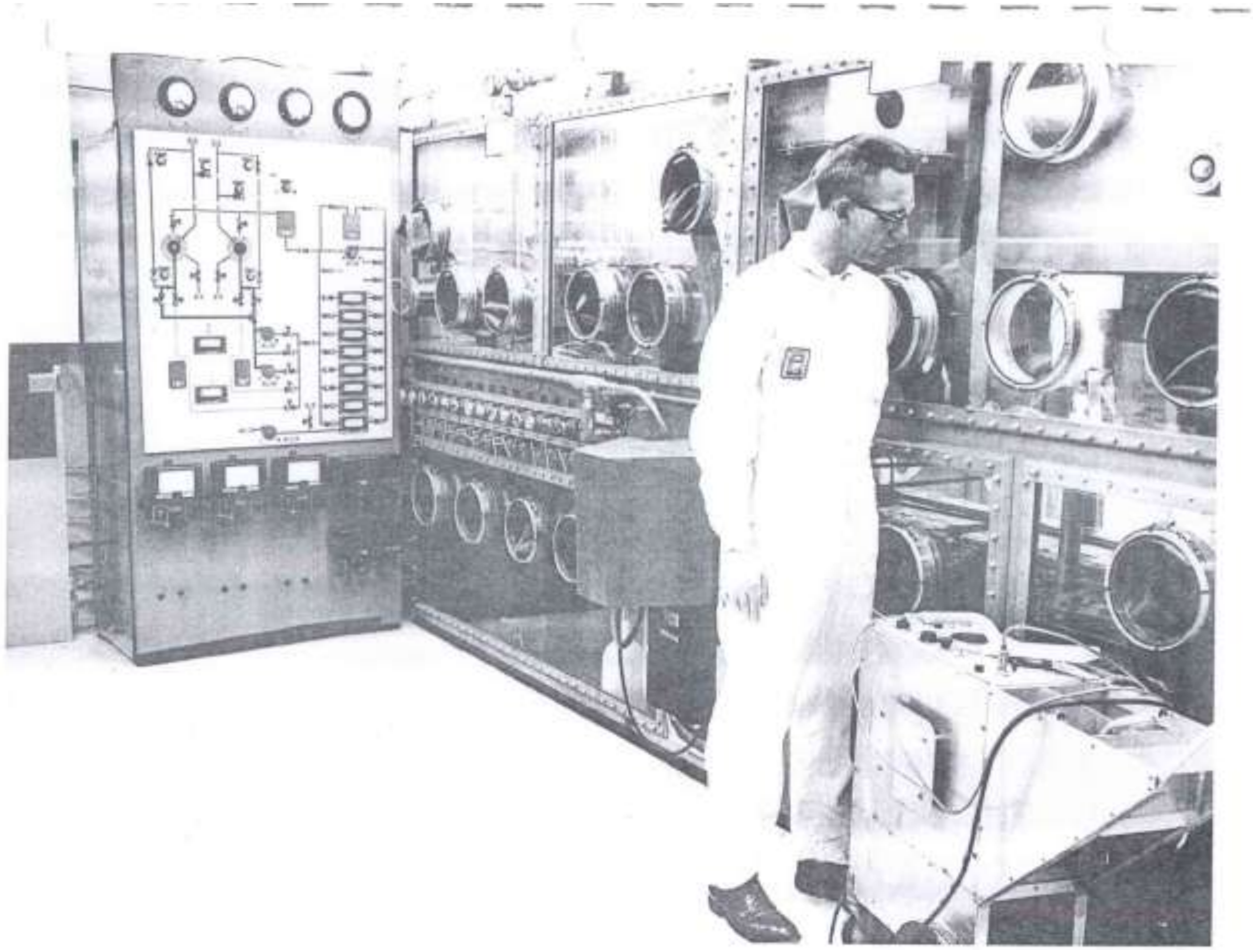

Figure 9. Glove Box Hood in Which Plutonium Solutions are Mixed in Criticality Safe Vessels

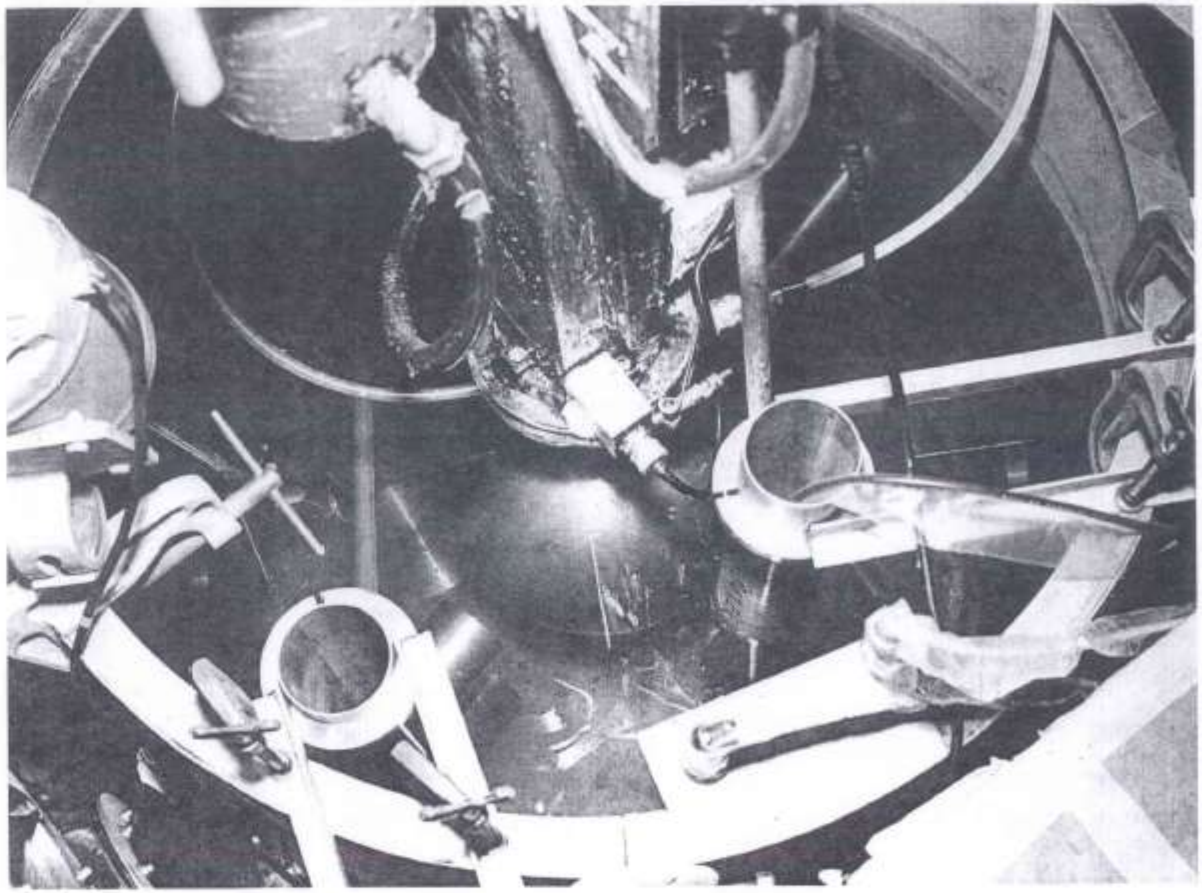

Figure 15. Spherical Vessel Submerged in Water for Measurement of Critical Concentrations Under These Conditions

Figure 13. Vessel for Studying Criticality of Solutions in Spherical Geometry with Concrete Reflector Partially Removed

Figure 17. Cylindrical Vessel Being Set Up for Criticality Studies with Solutions

Figure 16. Large Spherical Vessel Used for Determining Eta for Plutonium and Infinite Sea Critical Concentration

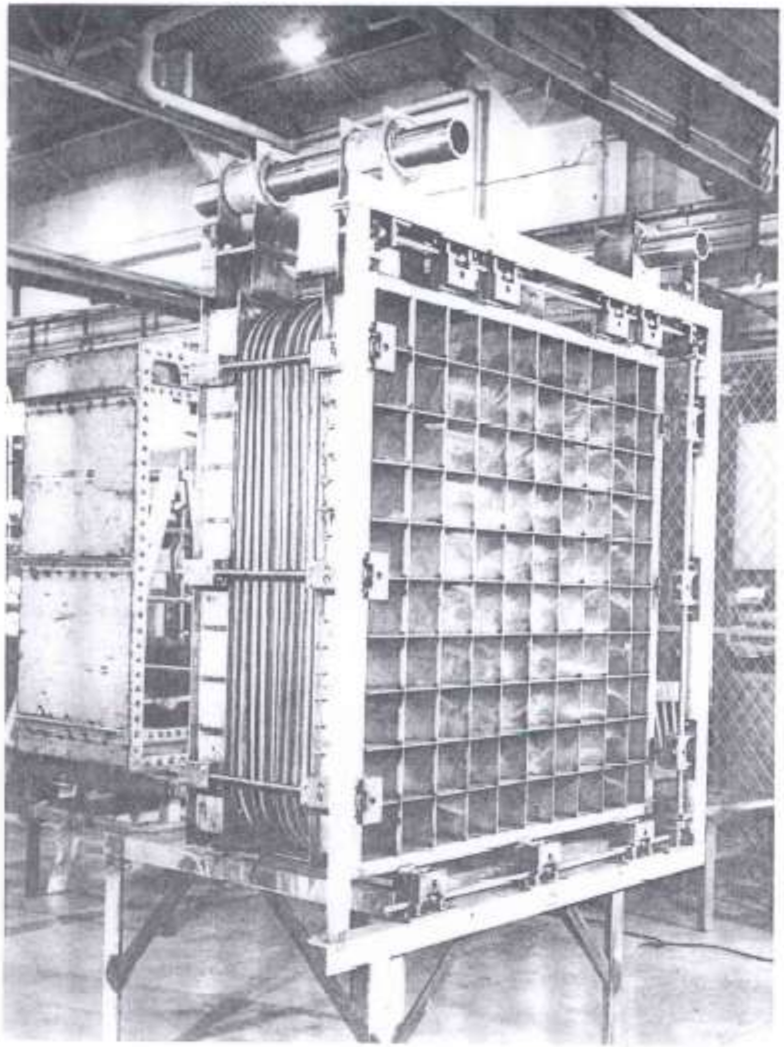

Figure 18. Variable Thickness Slab-Type Assembly

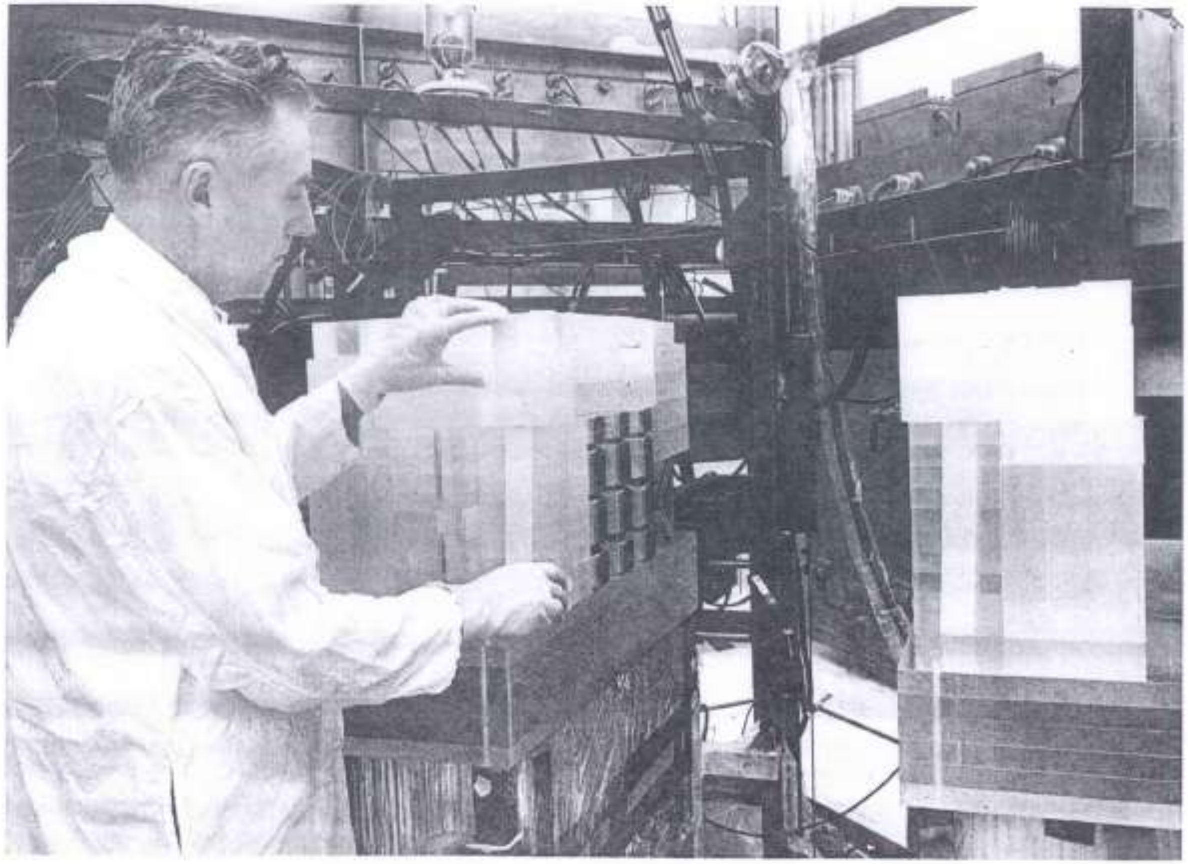

Figure 31. Criticality of Arrays of Pu Metal

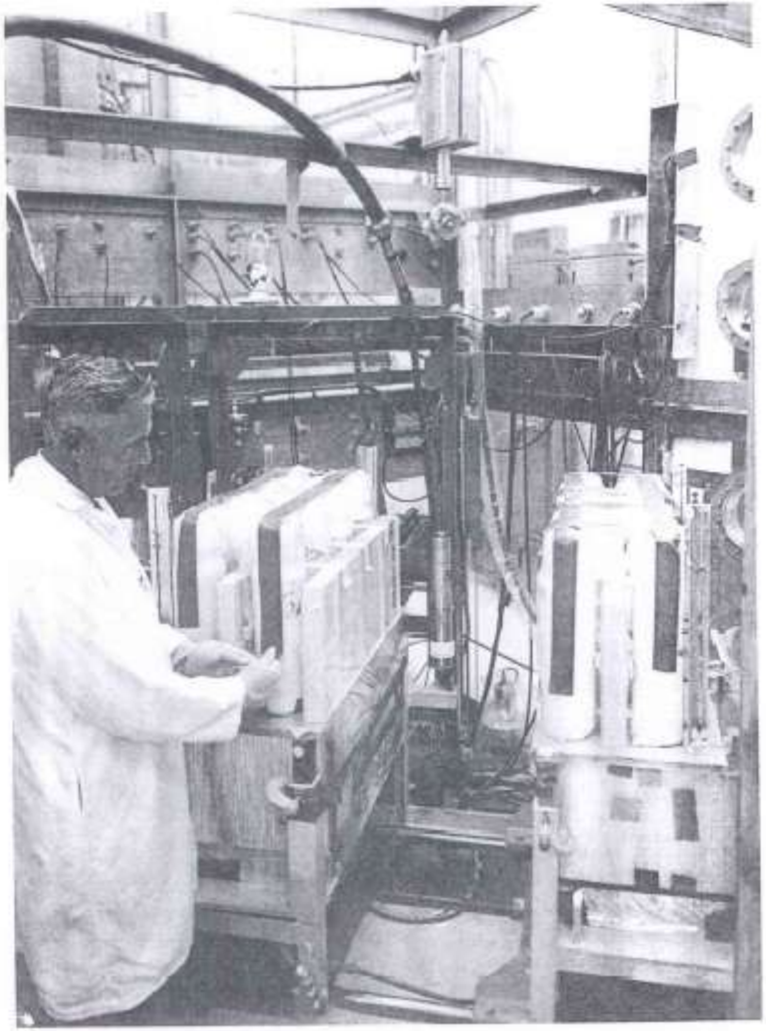

Figure 30. Criticality of Arrays of ^{233}U Solution (16-Bottle Moderated Unreflected Array of ^{233}U Solution)

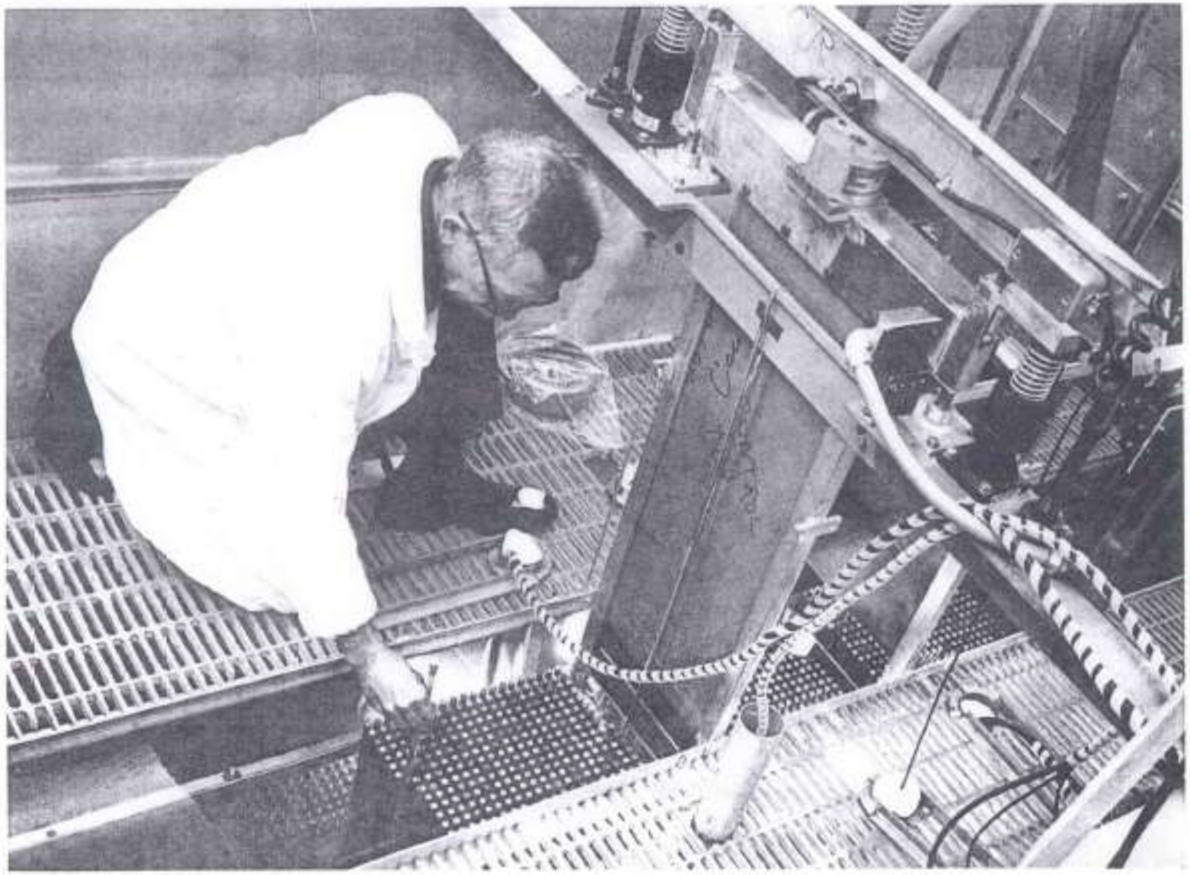

Figure 25. Criticality Studies of Interacting Arrays of Low Enriched Uranium Fuel Assemblies Under Water

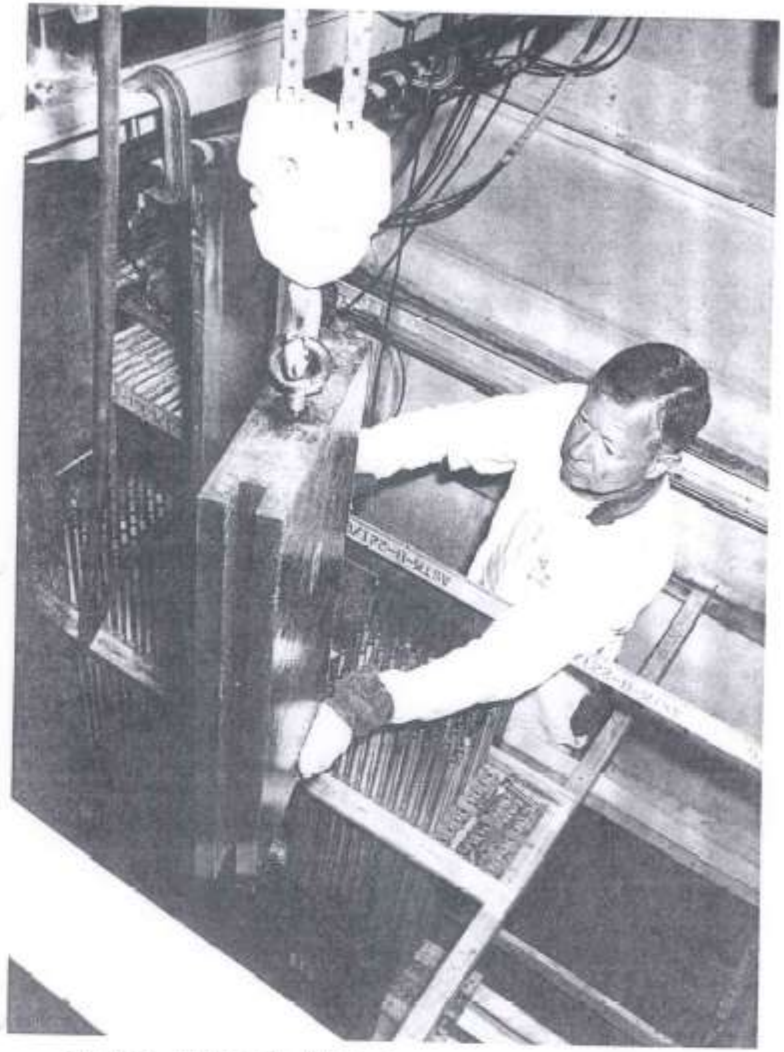

Figure 26. Portion of Depleted Uranium Reflector Being Positioned for Experiments on Criticality of Arrays of Fuel Elements

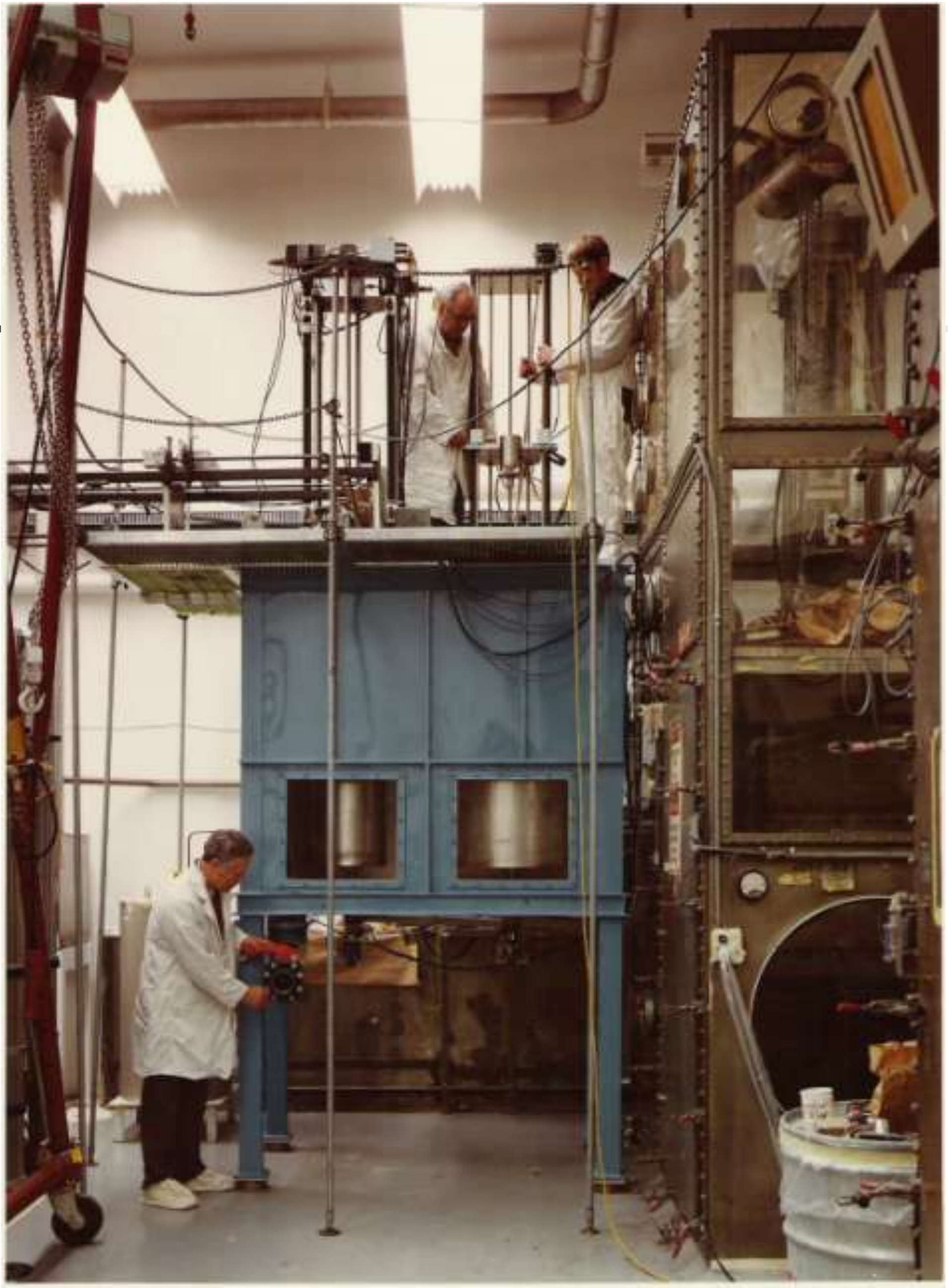

Figure 32. Subcritical Neutron Multiplication Measurements on Arrays of Storage Containers for Plutonium Nitrate Solution

Figure 35. Pulsed Neutron Source Experiments in the Field

(of waste cribs to determine degree of sub-criticality)

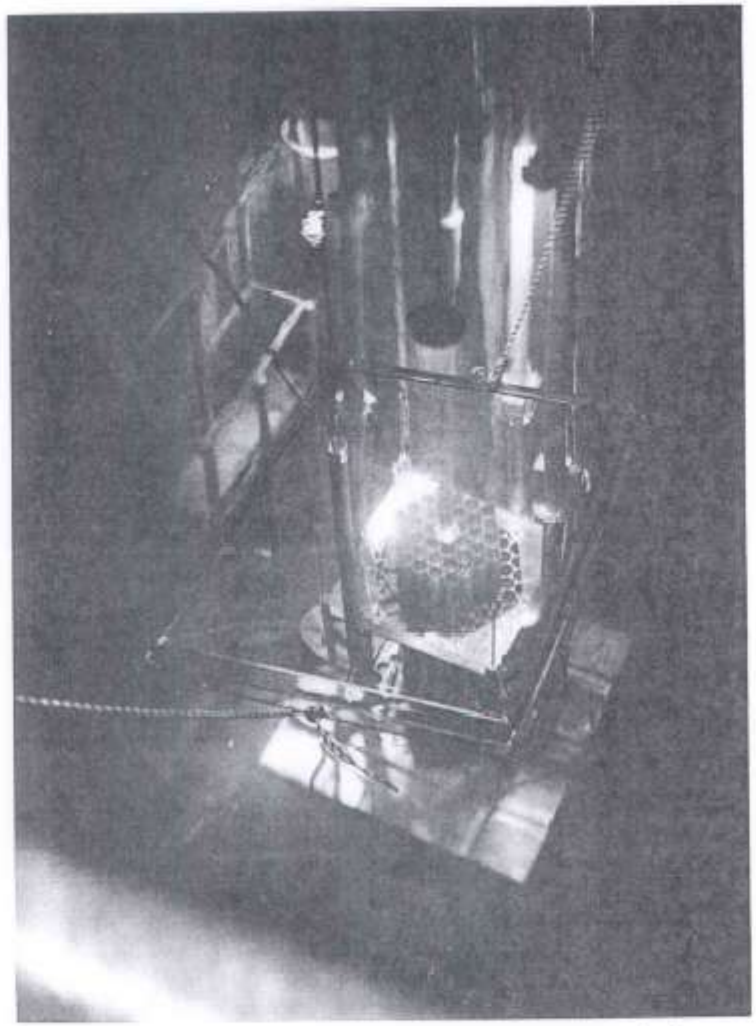

Figure 37. Pulsed Neutron Source Experiments in the Fuel Storage Basin at N Reactor (to determine number to go "critical")

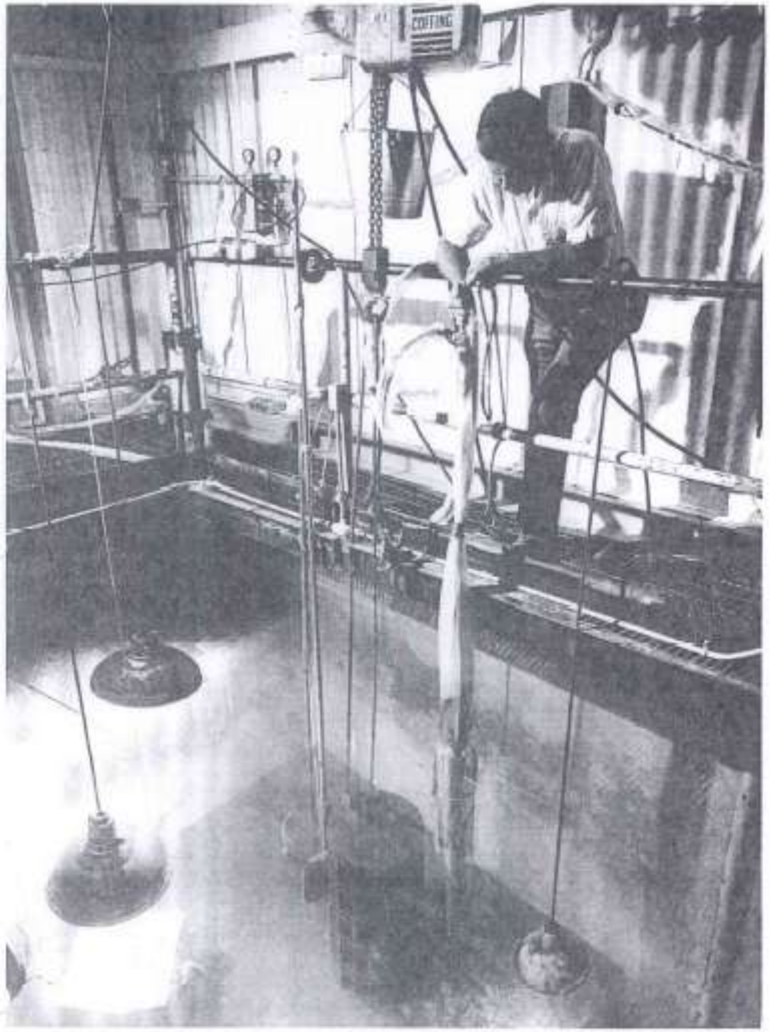

Figure 38. Neutron Generator Head Being Positioned for Pulsed Neutron Source Experiment on Assembly of High Exposure Fuel Elements

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Now that you have a better understanding of how we collected the data, let's look at the "Anomalies…."

- There are several "basic limits" talked about in "Anomalies…" that you utilize as controls on a daily, routine basis. Look at for example, the minimum critical mass for plutonium and uranium.

Let me illustrate (cont.)….

- The standards commonly quote a minimum critical mass of plutonium-239 in water of 531g. Likewise, for uranium it is found to be 820g. The critical concentrations at which these occur are 33g/l Pu and 55g/l U in their respective mixtures.

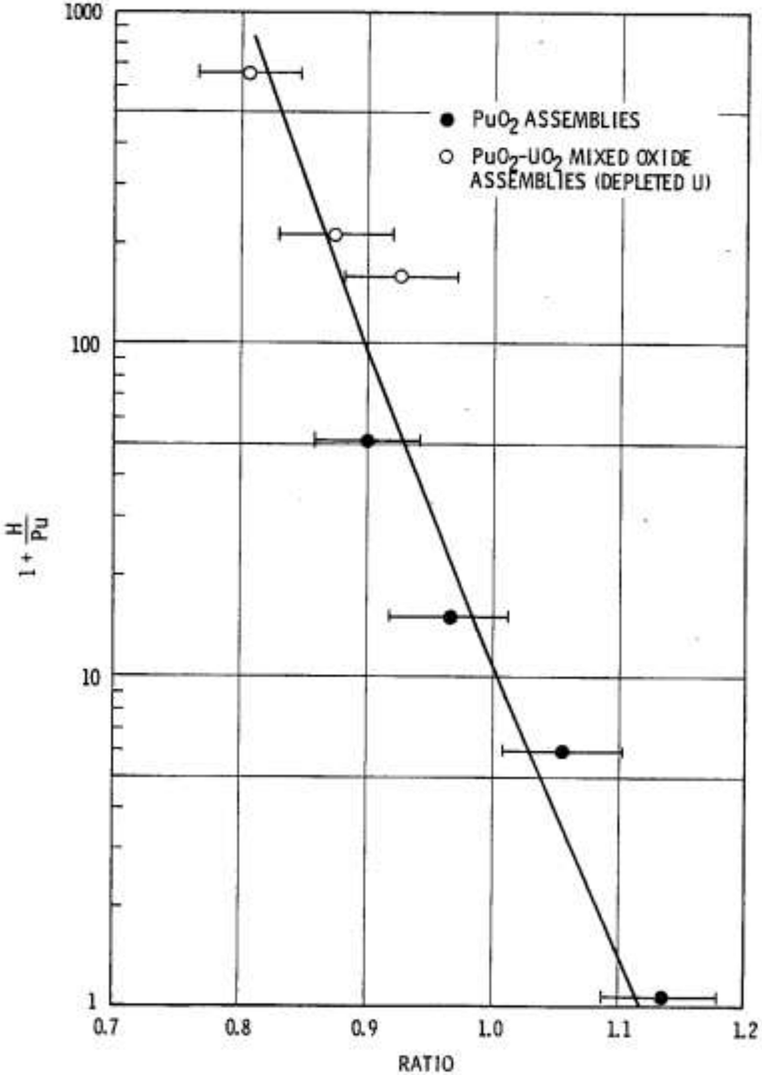
Let me illustrate (cont.)….

- But did you know that this is not the smallest critical mass possible?
- Did you know that if either Pu or U is admixed with a different hydrogenous material such as polyethylene, that this number can be reduced to as low as 370g for Pu?
- With a beryllium reflector, it can be much less.
- "Anomalies…" tells about this

And, to illustrate further….

- Another common misconception is that the minimum critical mass always occurs for a spherical shape.
- Yet, "Anomalies" points out that in some instances, this is not true such as in the following figure.

And, to illustrate further….



Another…..

- We all know that adding neutron poisons will bring us “further from critical” in all instances – Right?
- Yet in “Anomalies” we see that for some arrays of fuel rods, the addition of a typical neutron poison such as boron or gadolinium can in fact decrease or improve the effectiveness of other poisons present.

Examples…..

- "Anomalies" points out that in a highly under-moderated array of fuel rods, the addition of more boron may in fact increase the reactivity of the system.
- For water moderated plutonium and plutonium nitrate spheres, in an under-moderated condition, it takes more "poison" to drive the sphere sub-critical for the nitrate solution
- For soil mixtures admixed with plutonium, small amounts of water and cadmium, there is indication that the addition of "more cadmium" may not necessarily be better.

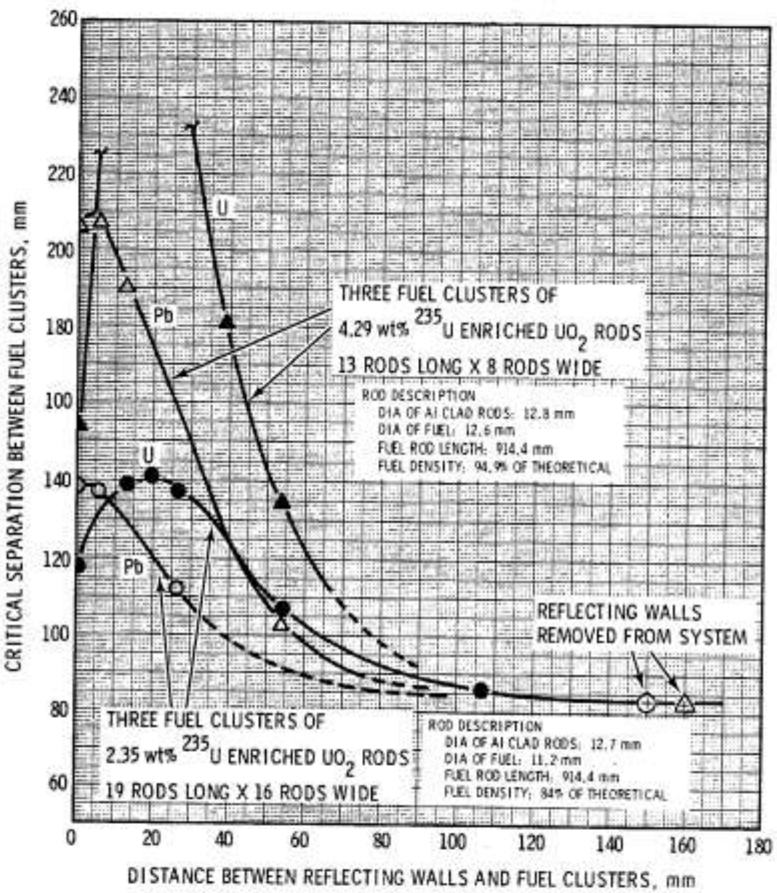
Poisons always stay in solution – Right?

- In one experiment I performed in 1978, I was adding cadmium as a neutron poison.
- Approach to critical was on fuel rod number vs. poison added.
- Backed off to subcritical at end of day
- Next day, observed all of the cadmium had precipitated out on tank bottom
- Reason was due to slight basic nature of water, resulting in the formation of hydroxides. When acid was added, it went back into solution.

One More….

- How about the common belief that the full-concrete or water reflector gives us the optimum reflection conditions?
- Yet, “Anomalies” shows us that composite reflectors are far better. In fact, in some instances, a little bit of water and a lot of heavy metal can make a substantial difference.

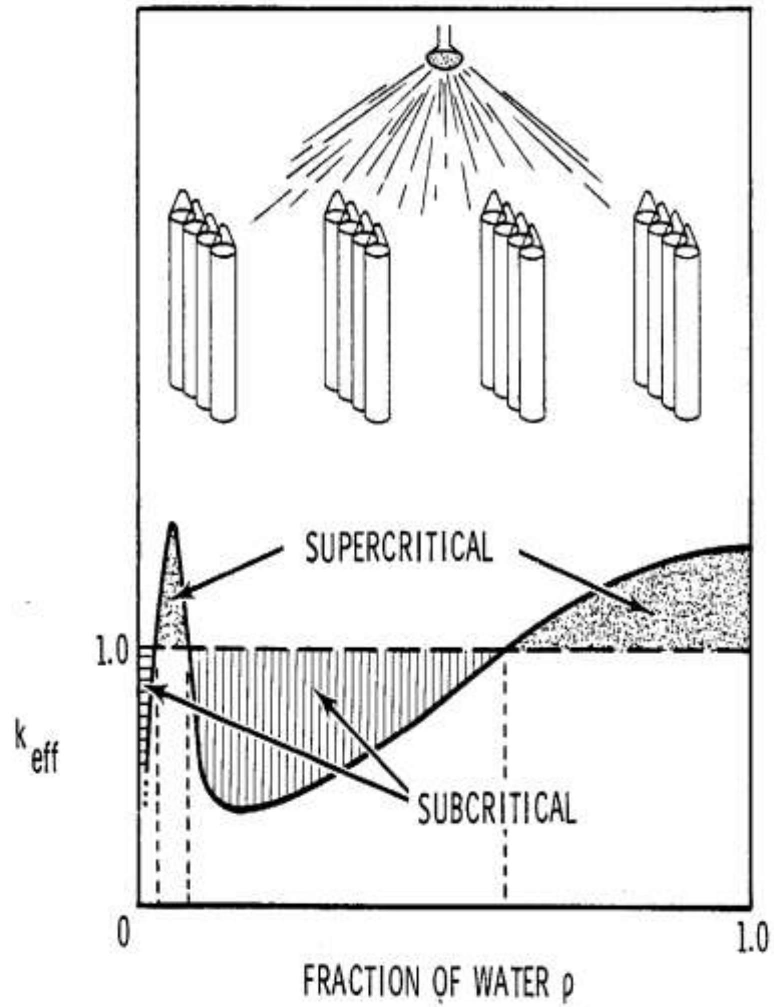
The Composite Reflector Compared to Full-Water Reflector



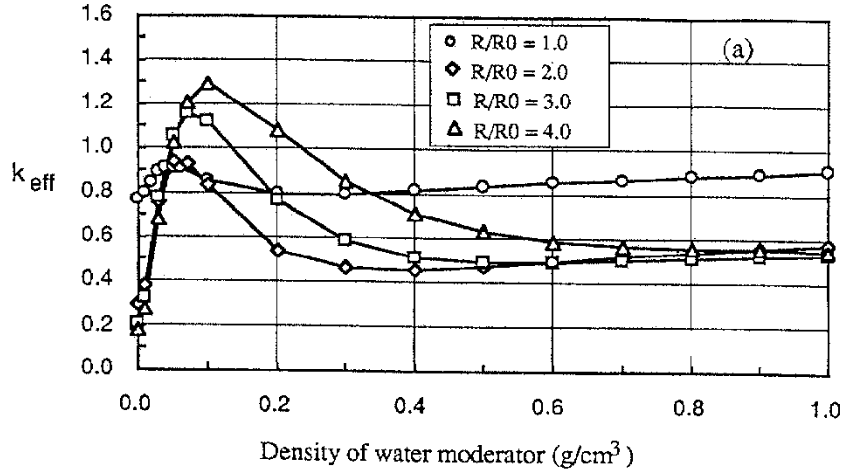
And then….

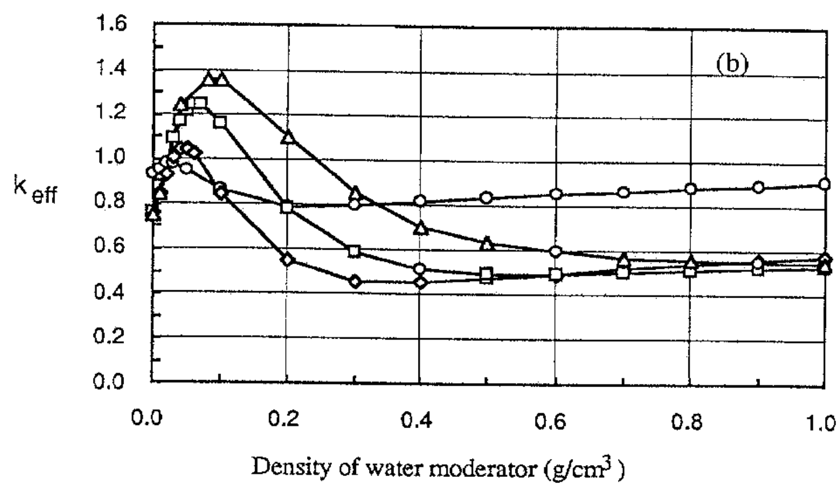
- Fully moderated is surely always the most reactive condition?
- Yet, “Anomalies” illustrates that sometimes the most reactive condition occurs with partial interstitial moderation.
- Need to consider for sprinkler applications.

Increased Reactivity with Interstitial Moderation



A Specific Example from Anomalies ……





So, in finishing this talk…

- I hope you see why I believe it is important for you to know this information.
- I am growing older and the lessons that I learned as an experimenter and analyst must be transferred to you who will lead the “New Power Revolution” that is about to occur.

In the next ten years….

- You will see the rebirth of Nuclear Power
- You will see the re-licensing of dozens of existing nuclear power stations world-wide
- You will see the licensing of perhaps dozens of brand new power stations
- You will see the creation of new reprocessing plants and enrichment facilities
- The renaissance will be world-wide
- In every instance, there will be a need for criticality expertise and the safe storage of nuclear fissile materials.

Thus,

- With the operation of new facilities, there will be an ever increasing potential to miss-handle nuclear fissile materials.
- You will be the gate keepers to prevent accidents from occurring.
- But, you will do this only if you know how to prevent the "anomalies from occurring".

So, in conclusion…..

- I plead for everyone present today to re-acquaint themselves with the “Anomalies of Criticality”.
- If you aren’t presently, I ask you to formally adopt it as required reading in your training programs.
- Finally, I ask you to continue the tradition of adding to its compendium as did Dr. Clayton. You can only prevent what you know to be a hazard.
- From our perspective, we hope to issue the Rev. 6 version of “Anomalies of Criticality” shortly.

I would like to thank…

- Raymond Puigh and his staff at Fluor whose efforts were key to bringing this revision of “Anomalies” to publication.
- Ray tells me that it should be available soon.
- If possible, Bechtel publications will also issue the document as a hard-bound volume for training use.

And of course…..

- Last and most important, I would like to publically Thank Duane for his tireless effort in this life-time work of collecting the "Anomalies".
- This document will continue to stand as a legacy to him - a life well-spent to the benefit of mankind.